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RESEARCH MEMORANDUM

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Air Materiel Command, Army Air Forces

INVESTIGATION OF OPERATING CHARACTERISTICS OF AN ENGINE EQUIPPED WITH MODIFICATIONS TO ELIMINATE FUEL-EVAPORATION ICING

By Donald R. Mulholland and Edward D. Zlotowski

Aircraft Engine Research Laboratory
Cleveland, Ohio

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INVESTIGATION OF OPERATING CHARACTERISTICS OF AN ENGINE EQUIPPED WITH MODIFICATIONS TO ELIMINATE FUEL-EVAPORATION ICING

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SUMMARY

Two modified fuel-injection systems, a drilled-inducer type and a spinner type, that prevent serious fuel-evaporation icing were installed on a V-type, liquid-cooled aircraft engine and a preliminary investigation was conducted to determine the effect on engine operating characteristics. The spinner system was also ground- and flight-tested on a twin-engine fighter airplane. Flight measurements of cylinder-head temperatures over a range of fuel-air ratios and engine power conditions were made at an altitude of approximately 10,000 feet.

Starting and acceleration of the engine on the ground were unaffected by the fuel-injection modifications. During the flight investigation, no appreciable variation occurred between the maximum and minimum cylinder-head temperatures with the standard and modified system for the same power condition and no irregularity of mixture distribution could be detected throughout the power range of the engine Normal mixture distribution was also indicated by a similar response of cylinder-head temperatures for variations of fuel-air ratio at manifold pressures of 25 and 35 inches of mercury absolute.

Both modified fuel-injection systems required less fuel-nozzle pressure than the standard system to obtain the desired fuel-air ratio for a given air-flow condition.

INTRODUCTION

An investigation of the icing characteristics of an aircraft-engine induction system in a laboratory setup consisting of a supercharger assembly and a carburetor resulted in the design of two

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fuel-injection modifications, a spinner fuel-injection system and a drilled-inducer fuel-injection system, both of which satisfactorily prevent the formation of fuel-evaporation icing (references 1 and 2).

An electric motor was used to drive the engine-stage supercharger during icing investigations to avoid operation of the entire engine. The investigation was extended, using both fuel-injection modifications on a full-scale laboratory engine, to determine whether the modifications affected carburetor metering and general engine performance. The spinner system was further investigated on an airplane during ground and flight tests to obtain a comparison of engine operation with the standard system.

The results are based on observations of the ease of starting and acceleration of the engine, as well as on measurement of the cylinder-head temperatures, which roughly indicate the nature of mixture distribution to the cylinders.

APPARATUS AND PROCEDURE

Spinner and drilled-inducer fuel-injection systems. - In the spinner fuel-injection system (fig. 1), the fuel passes from the standard injection nozzle through a special fuel-transfer tube to a spinner that is mounted on a special externally threaded impeller retaining nut. The fuel is radially discharged by centrifugal force into the spaces between the vanes at the face of the impeller.

The drilled-inducer fuel-injection system (fig. 2) is similar to the spinner system except that the fuel passes from a spinner through drilled passages in the inducer part of the impeller and is then discharged between the impeller vanes approximately thirteen-sixteenths inch from the impeller face.

Details of the parts used for each modification are given in reference 2.

Preliminary engine tests. - A multicylinder engine was operated in the laboratory with both modified systems prior to installation on the airplane in order to insure satisfactory flight operation. A water brake was used to absorb and measure the power output; an orifice was provided for measuring induction-system air flow; and a rotameter was installed in the fuel system for fuel-flow measurement. Thermocouples were used to measure carburetor-inlet-air temperature and supercharger-outlet mixture temperature. Manifold pressure and exhaust back pressure were indicated on mercury manometers and fuel-nozzle pressure was indicated on a pressure gage.

Ground and flight tests. - A detailed description of the installation and instrumentation of the V-type, liquid-cooled aircraft engine used in the twin-engine fighter airplane for a previous investigation of induction-system icing is given in reference 3 and much of the same instrumentation and equipment was used for this investigation. In addition, thermocouples were installed in the cylinder heads approximately three-sixteenths inch from the inner surface of the combustion chamber between the exhaust-valve seats. (See fig. 3.)

Instrumentation was provided to measure free-air temperature, pressure altitude, and airspeed. For the engine, instrumentation was installed to measure engine speed, carburetor-inlet-air temperature and pressure, manifold mixture temperature and pressure, cylinder-head temperatures, compensated and uncompensated metering suction differential pressure, mixture setting, coolant temperature, and cooling-air temperature.

Pressures and temperatures were recorded by standard NACA pressure recorders and a recording potentiometer, respectively.

The uncompensated metering suction differential pressure of the specially calibrated carburetor was used to determine the charge-air flow through the carburetor, and the compensated metering suction differential pressure to determine fuel flow. A special mixture-control disk was installed on the carburetor to obtain accurate fuel-air-ratio control and a differential-pressure gage was installed in the cockpit to indicate the compensated metering suction differential and thus enable the pilot to set desired fuel-air ratios.

Prior to flight, a ground check was made of engine performance with spinner fuel injection throughout the power range from idling to take-off power in order to insure smooth and detonation-free operation.

Comparative flights were made at an altitude of approximately 10,000 feet with the spinner fuel-injection system and the standard system. The drilled-inducer fuel-injection system was not investigated in flight.

The program included flights at low-cruise and high-cruise power conditions with varying fuel-air ratio and flights at various powers up to rated engine power with specified fuel-air ratios. Ease of starting and acceleration were noted throughout the investigation. Data were recorded for each $3\frac{1}{2}$-minute period after conditions were stabilized.

RESULTS AND DISCUSSION

Data obtained from operation of the laboratory engine with both modified fuel-injection systems and with the standard system are compared in table I. Over the power range investigated, engine operation was satisfactory with either of the modified injection systems.

An effect of the two modified fuel-injection systems on carburetor metering characteristics is indicated by variations from the standard fuel-nozzle pressure, as shown in table I. The fact that operation with both modified systems resulted in lower fuel-nozzle pressure for a given fuel flow at constant air-flow conditions is partly attributed to the reduction in back pressure obtained by cropping the pintle head of the standard fuel nozzle (figs. 1 and 2). On a standard carburetor without variable mixture-control disks, the effect of the reduced fuel-nozzle pressure of the modified systems would be an increase in fuel-air ratio and would require appropriate adjustments in metering jets.

No apparent change in general engine operating characteristics occurred during the ground tests using spinner fuel injection throughout the entire power range from idling to take-off. Ease of starting was not affected at the prevailing carburetor-air temperatures (52° to 76° F) and no adverse effect on engine acceleration was detected.

The maximum and minimum cylinder-head temperatures and temperature spread resulting from two of the flights at an approximate altitude of 10,000 feet are presented in the following table for both the standard and spinner fuel-injection systems throughout the range of engine power:

Flight	Run	Manifold pressure (in. Hg absolute)	Engine speed (rpm)	Temperature (°F)				
				Coolant	Carburetor inlet air	Cylinder head		
						Maximum	Minimum	Spread
Standard fuel injection								
3	1	24.9	2200	225	57	401	340	61
3	2	29.9	2180	223	62	419	347	72
3	3	35.2	2240	222	67	448	367	81
3	4	39.9	2540	222	77	450	368	82
3	5	43.2	2540	221	82	452	371	81
3	6	50.1	2800	222	92	472	383	89
3	7	53.8	2940	224	100	485	392	93
Spinner fuel injection								
1	1	24.6	2180	224	55	403	340	63
1	2	30.0	2160	221	54	426	352	74
1	3	34.7	2280	223	64	453	373	80
1	4	39.7	2580	221	74	452	371	81
1	5	42.7	2580	221	79	458	376	82
1	6	49.8	2800	220	93	496	389	107
1	7	53.7	2960	222	94	492	399	93

No appreciable variation in the spread of maximum and minimum cylinder-head temperatures occurred at a given power condition for the standard and spinner fuel-injection systems except between the comparable runs at manifold pressures of 50.1 and 49.8 inches of mercury absolute and engine speed of 2800 rpm where an unaccountable variation of 18° F occurred. For the remaining six power conditions, the maximum difference in spread was only 2° F. Because of the small average variation between the spread of maximum and minimum cylinder-head temperatures for both fuel systems, it can be concluded that the spinner fuel-injection system caused no adverse effect on mixture distribution. The spread between maximum and minimum cylinder-head temperatures for a given engine power condition cannot be taken as a direct criterion of the uniformity of mixture distribution because the thermocouple installation in the cylinder heads, although suitable for comparing the effects of a change in fuel-air ratio, was not accurate enough for an absolute evaluation of mixture distribution.

When other conditions are equal, uniform mixture distribution in a multicylinder engine insures similar response of each cylinder temperature to variations of fuel-air ratio. On this basis, the spinner fuel-injection system gave slightly better results than the standard system. A comparison of individual cylinder-head temperatures with

varying fuel-air ratios at manifold pressures of 25 and 35 inches of mercury absolute is presented in figure 4. At the low power condition (fig. 4(a)), no appreciable deviation between the trends of cylinder-head temperatures occurred for either fuel-injection system. At the high power condition (fig. 4(b)) when the standard system was used, however, cylinders 4L and 5R did not show responses similar to the other cylinders; whereas, the use of the spinner fuel-injection system resulted in uniform response of all cylinders over the fuel-air-ratio range.

Figure 5 presents a comparison of cylinder-head temperatures throughout the range of engine operating conditions for each of the fuel systems. Differences in coolant temperature, carburetor-inlet-air temperature, and fuel-air ratio noted with the curves account for small changes in cylinder-head temperature; however, the curves for spinner and standard fuel injection for each power condition closely follow the same pattern indicating that the spinner fuel injection caused no adverse effect on mixture distribution over the power range of the engine.

Complete flight test data are given in table II.

SUMMARY OF RESULTS

The operational characteristics of two modified fuel-injection systems that have been shown to reduce the icing associated with fuel evaporation were investigated on ground test stands and in flight and the following results were obtained:

1. The spinner fuel-injection system did not affect engine starting and acceleration characteristics on the ground.

2. During the flight investigation, spinner fuel injection produced a spread between maximum and minimum cylinder-head temperatures within 2° F of that obtained with the standard system except for one power condition where the spread of the former was 18° F higher.

3. Variation of fuel-air ratio at manifold pressures of 25 and 35 inches of mercury absolute using spinner fuel injection produced a similar response of all cylinder-head temperatures indicating uniform mixture distribution.

4. Throughout the power range of the engine, spinner fuel injection caused no significant change in mixture distribution based on a comparison of individual cylinder-head temperatures.

5. Both modified fuel-injection systems operated with less fuel-nozzle pressure than the standard system required and appropriate adjustments in metering jets would be necessary to maintain normal metering characteristics of the carburetor with standard mixture-control disks.

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2. Mulholland, Donald R., and Chapman, Gilbert E.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of the Lockheed P-38J Airplane. VI - Effect of Modifications to Fuel-Spray Nozzle on Icing Characteristics. NACA MR No. E6A23, Army Air Forces, 1946.

3. Essex, Henry A., Zlotowski, Edward D., and Ellisman, Carl: Investigation of Ice Formation in the Induction System of a Lockheed P-38J Airplane. I - Ground Tests. NACA MR No. E6B28, Army Air Forces, 1946.

TABLE I - COMPARISON OF ENGINE OPERATION WITH STANDARD AND MODIFIED FUEL-INJECTION SYSTEMS

Run	Engine speed (rpm)	Manifold pressure (in. Hg absolute)	Mixture setting	Air flow (lb/sec)	Fuel flow (lb/sec)	Fuel-air ratio	Brake horse-power	Exhaust back pressure (in. Hg absolute)	Carbu-retor-inlet-air temper-ature (°F)	Super-charger-outlet temper-ature (°F)	Fuel-pump pres-sure (lb/sq in.)	Fuel-nozzle pres-sure (lb/sq in.)
Standard fuel injection												
68	1600	25.2	Auto. lean	0.70	0.052	0.075	383	29.98	68	82	17.0	4.0
69	1870	25.2	Auto. lean	.75	.056	.075	403	30.08	68	95	17.5	4.0
70	2300	32.0	Auto. rich	1.32	.103	.078	697	31.63	70	113	18.0	3.7
71	2300	32.2	Auto. lean	1.31	.095	.072	697	31.63	71	117	18.0	3.6
72.	2600	39.8	Auto. rich	1.90	.175	.092	981	33.78	71	118	18.0	3.0
73	3000	40.0	Auto. rich	2.04	.183	.089	971	34.63	72	152	18.5	2.9
Spinner fuel injection												
52	1600	25.0	Auto. lean	0.71	0.052	0.073	378	29.70	57	80	17.0	3.5
53	1870	25.2	Auto. lean	.80	.057	.071	413	29.70	52	88	18.0	3.5
55	2300	31.8	Auto. rich	1.29	.100	.077	683	31.20	50	100	18.0	3.3
54	2300	32.0	Auto. lean	1.29	.092	.071	679	31.20	50	104	18.0	3.2
56	2600	40.0	Auto. rich	1.94	.169	.086	984	33.30	50	100	18.0	2.9
57	3000	40.0	Auto. rich	1.98	.182	.092	951	33.70	48	132	18.5	2.7
Drilled-inducer fuel injection												
58	1600	25.0	Auto. lean	0.69	0.052	0.075	372	29.90	80	94	17.4	3.2
59	1870	25.2	Auto. lean	.77	.057	.074	405	29.95	77	103	17.5	3.2
60	2300	32.2	Auto. rich	1.34	.104	.078	700	31.70	75	117	18.0	2.9
61	2300	31.9	Auto. lean	1.30	.097	.074	683	31.68	80	123	18.0	2.9
62	2600	40.1	Auto. rich	1.90	.168	.088	970	33.70	78	126	18.0	2.4
63	3000	40.2	Auto. rich	2.01	.182	.090	951	34.40	85	160	18.0	2.1

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TABLE II - RESULTS OF FLIGHT INVESTIGATION OF STANDARD AND SPINNER FUEL-INJECTION SYSTEMS ON V-TYPE, LIQUID-COOLED AIRCRAFT ENGINE

Flight and run	Fuel system	True free-air temp. (°F)	Pressure altitude (ft)	True air-speed (mph)	Engine speed (rpm)	Manifold pressure (in. Hg abs.)	Carburetor-deck pressure (in. Hg abs.)	Charge-air flow (lb/hr)	Fuel flow (lb/hr)	Fuel-air ratio	Temperature (°F)					Cylinder-head temperature (°F)											
											Cooling air	Coolant	Fuel	Carburetor inlet air	Mixture at manifold	Right bank						Left bank					
																1	2	3	4	5	6	1	2	3	4	5	6
1-1	Spinner	38	9,990	234	2180	24.6	21.1	3829	242	0.063	45	224	78	55	111	402	401	403	396	388	383	400	340	396	397	383	362
2		36	10,070	266	2160	30.0	21.3	4859	302	.062	45	221	72	54	103	411	424	426	416	405	404	419	352	414	417	397	377
3		36	10,090	290	2280	34.7	23.9	5755	399	.069	48	223	81	64	111	448	444	448	444	429	427	453	373	451	453	432	411
4		39	9,970	309	2580	39.7	25.2	7330	617	.084	52	221	71	74	128	443	443	443	444	424	424	452	371	448	448	429	406
5		37	10,080	317	2580	42.7	27.1	7874	678	.086	52	221	81	79	134	455	447	452	452	432	430	458	376	454	454	438	413
6		37	10,105	335	2800	49.8	29.3	9514	830	.087	51	220	81	93	165	496	476	476	474	456	453	480	389	476	473	456	424
7		36	10,080	339	2960	53.7	30.7	10432	896	.086	52	222	80	94	183	492	491	492	488	469	467	491	399	489	485	467	421
2-1	Spinner	47	10,145	229	2200	24.9	20.9	3867	244	0.063	54	221	80	65	118	395	395	395	395	387	385	396	337	393	395	386	364
2		46	10,170	237	2200	24.9	20.8	3862	268	.069	54	219	80	65	116	400	400	400	400	392	388	404	340	400	400	390	368
3		45	10,195	239	2200	24.8	20.8	3922	283	.072	50	222	74	61	110	397	397	397	397	391	386	401	340	399	399	389	369
4		45	10,090	236	2200	24.8	20.9	3856	290	.075	52	219	77	64	112	395	396	396	396	388	385	401	337	397	397	388	366
5		45	10,130	241	2200	25.0	20.9	3920	296	.076	51	219	74	62	107	394	394	394	394	388	384	400	337	398	398	389	368
6		45	10,105	236	2200	24.7	20.9	3906	300	.077	53	219	76	64	109	390	390	391	391	385	382	397	335	395	395	386	366
7		45	10,115	241	2200	24.9	20.9	3901	308	.079	52	219	75	62	107	387	387	388	388	382	379	397	335	393	393	384	363
8		45	10,130	285	2260	34.8	23.9	5650	358	.063	57	220	78	78	124	439	439	440	440	429	426	439	365	440	440	424	398
9		44	10,145	289	2280	34.8	23.9	5679	395	.070	57	220	77	78	119	441	441	441	441	430	427	443	367	446	446	430	403
10		44	10,195	290	2280	35.2	24.2	5715	405	.071	58	221	88	79	121	440	440	440	440	429	425	444	368	445	445	432	407
11		44	10,130	289	2280	34.8	23.9	5666	408	.072	57	217	78	78	117	433	433	433	433	424	420	439	363	440	440	425	400
12		44	10,130	290	2280	35.2	24.2	5714	412	.072	56	221	88	78	119	437	437	438	438	427	424	442	366	443	443	430	403
13		44	10,130	289	2280	34.8	23.9	5674	420	.074	57	219	78	78	114	433	433	433	433	425	421	439	363	440	440	426	401
14		44	10,130	290	2280	35.1	24.2	5729	433	.076	56	221	86	78	114	431	431	431	431	423	418	438	362	438	438	425	400
3-1	Standard	37	10,130	238	2200	24.9	20.9	3925	252	0.064	47	225	81	57	113	401	401	401	400	393	389	400	340	399	399	390	368
2		37	10,170	260	2180	29.9	21.0	4727	300	.064	47	223	73	62	109	419	418	419	413	403	402	411	347	412	412	399	376
3		35	10,145	290	2240	35.2	23.7	5793	403	.070	45	222	69	67	110	447	447	447	446	433	430	446	367	447	448	435	407
4		39	10,115	308	2540	39.9	25.1	7250	609	.084	53	222	70	77	132	449	448	449	449	431	429	449	368	450	446	430	404
5		38	10,145	320	2540	43.2	27.3	7837	680	.087	55	221	73	82	137	452	450	451	451	435	432	452	371	452	450	437	406
6		37	10,145	335	2800	50.1	29.3	9506	835	.088	54	222	72	92	167	468	468	470	470	458	454	471	383	472	467	455	422
7		32	10,145	340	2940	53.8	30.2	10409	905	.087	54	224	73	100	186	481	482	484	484	471	467	484	392	485	482	469	434
4-1	Standard	42	10,420	215	2200	24.8	20.7	3857	250	0.065	42	220	85	57	108	397	397	397	395	388	385	396	337	395	395	386	363
2		41	10,435	222	2200	24.8	20.7	3872	274	.071	40	119	80	55	106	400	404	400	400	391	389	401	339	398	398	390	366
3		42	10,485	219	2200	24.6	20.6	3820	283	.074	42	220	73	57	104	397	397	397	397	389	387	399	338	397	397	388	366
4		41	10,305	222	2240	24.6	20.6	3856	300	.078	42	219	72	57	101	391	391	391	391	383	382	397	336	392	392	384	363
5		42	10,345	225	2200	24.5	20.6	3867	314	.081	37	117	69	55	96	383	383	384	384	377	376	390	332	387	387	379	359
6		41	10,345	228	2200	24.6	20.8	3850	299	.078	42	218	70	56	101	391	391	391	391	384	381	395	336	392	392	384	363
7		40	10,230	225	2200	24.5	20.7	3865	288	.075	41	219	69	54	101	393	393	393	393	386	383	395	337	394	394	385	364
8		40	10,230	274	2280	34.8	23.8	5730	362	.063	45	218	73	63	110	438	438	438	438	425	423	435	363	435	435	420	396
9		40	10,155	273	2260	34.8	23.8	5743	400	.070	50	219	74	65	108	438	438	438	438	438	425	440	366	443	443	427	403
10		41	10,155	276	2260	34.7	23.7	5692	411	.072	49	216	74	66	107	437	437	437	437	426	423	440	365	440	440	425	403
11		41	10,155	275	2260	34.7	23.7	5757	421	.073	50	218	74	66	107	437	437	437	437	426	422	441	364	441	441	426	403
12		41	10,155	276	2280	34.7	23.7	5733	452	.079	49	219	72	66	104	427	425	426	426	419	417	434	361	434	434	422	399

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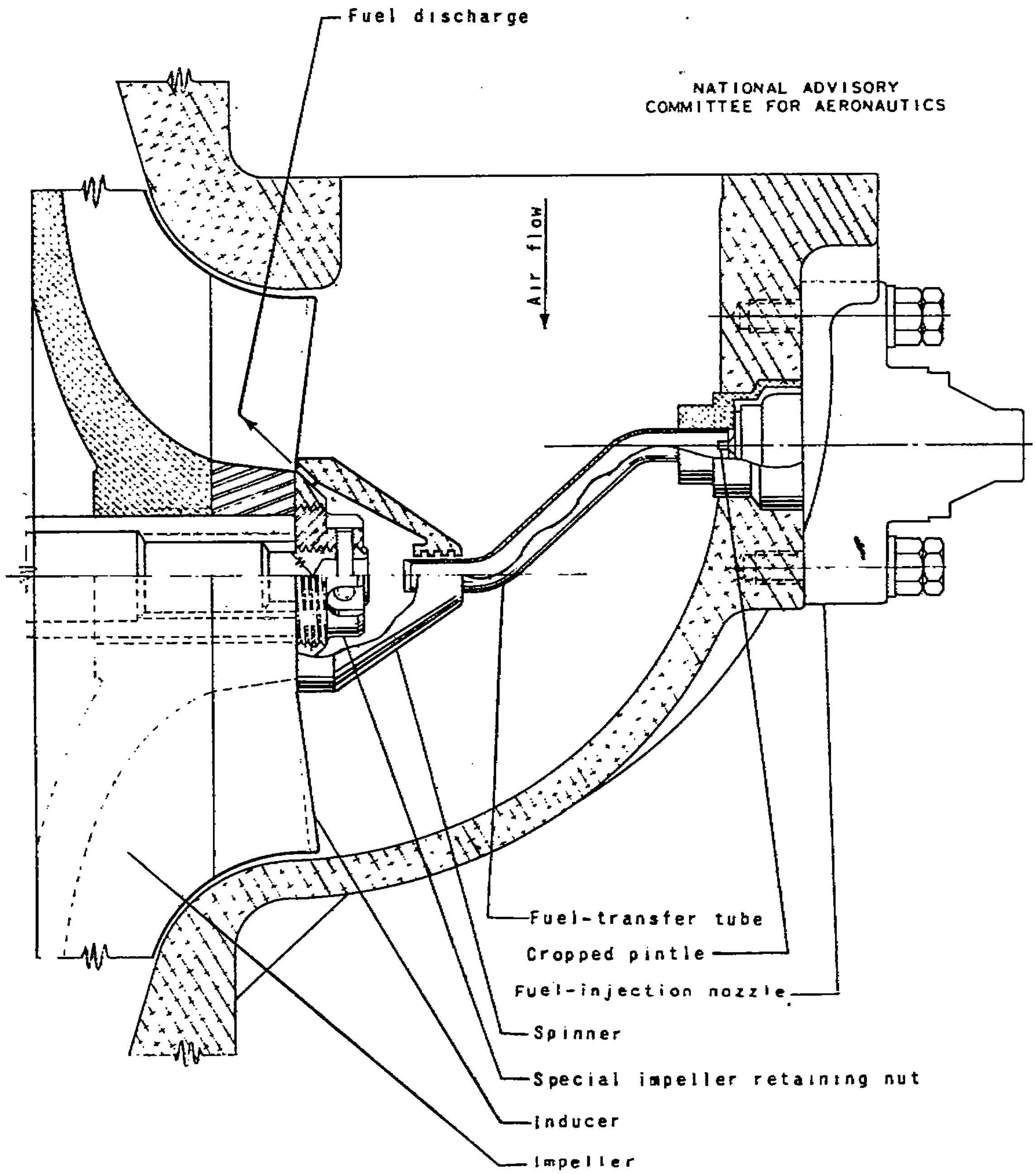

Figure 1. - Spinner fuel-injection system on V-type, liquid-cooled aircraft engine.

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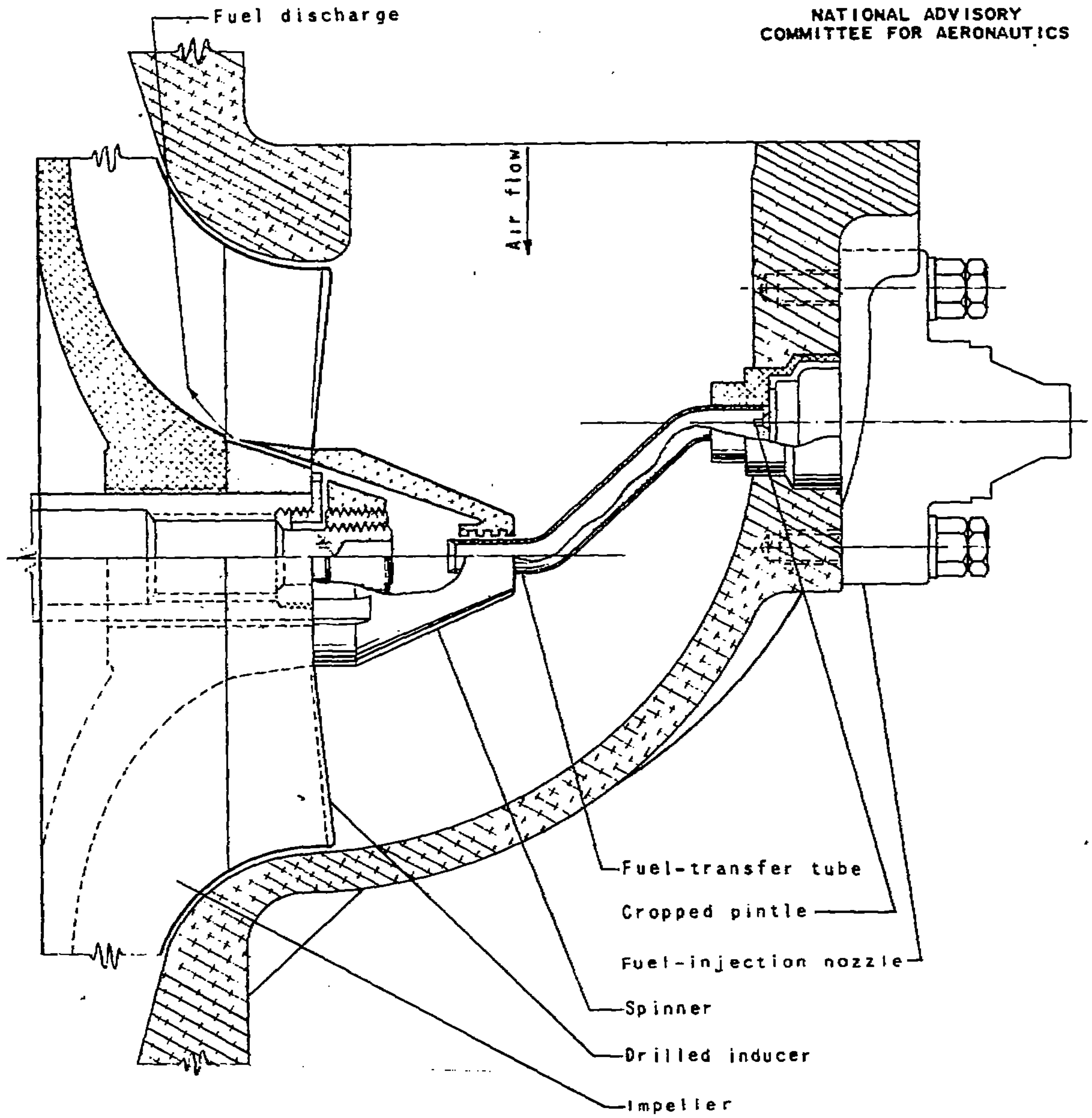


Figure 2. - Drilled-inducer fuel-injection system on V-type, liquid-cooled aircraft engine.

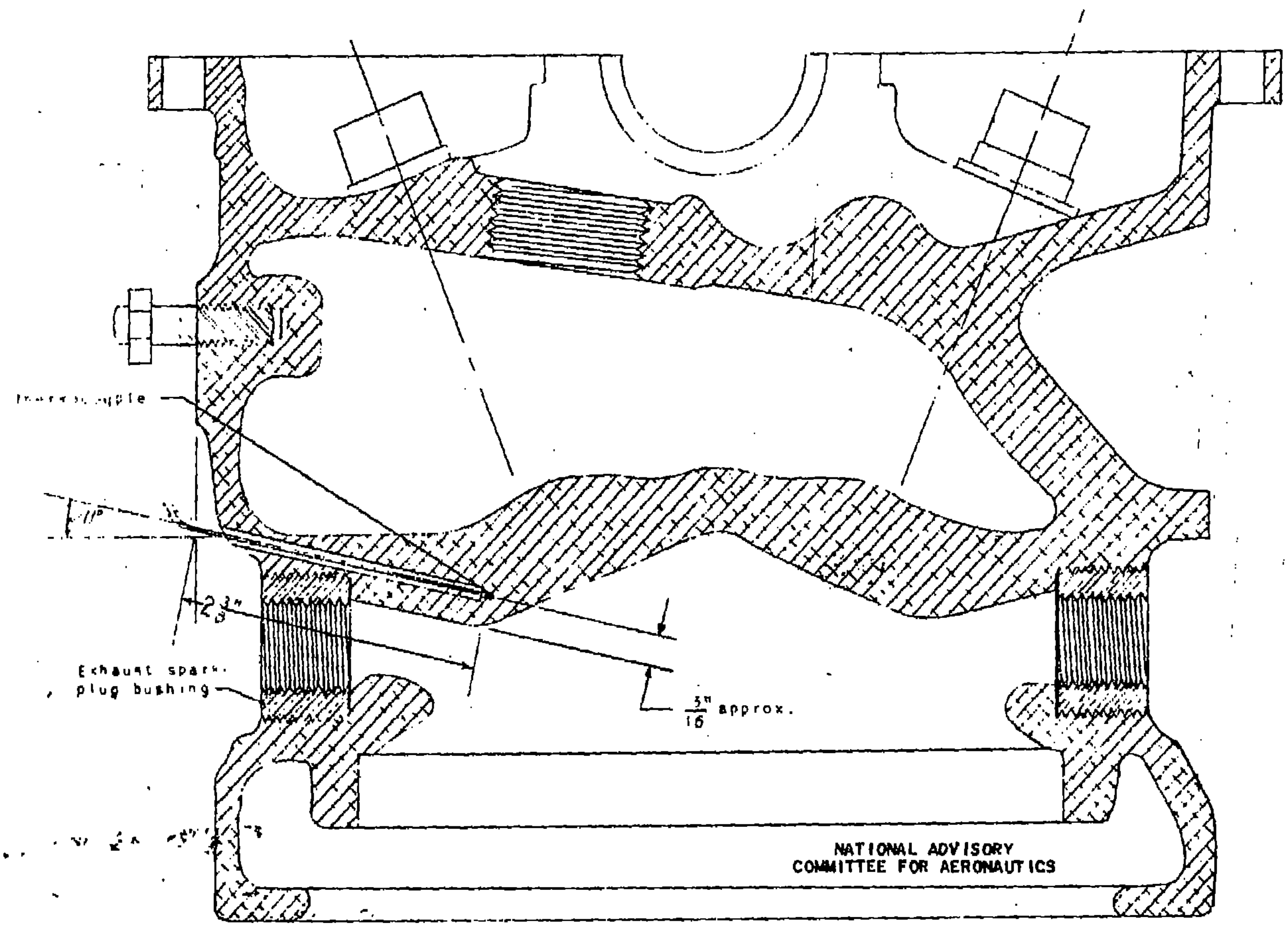
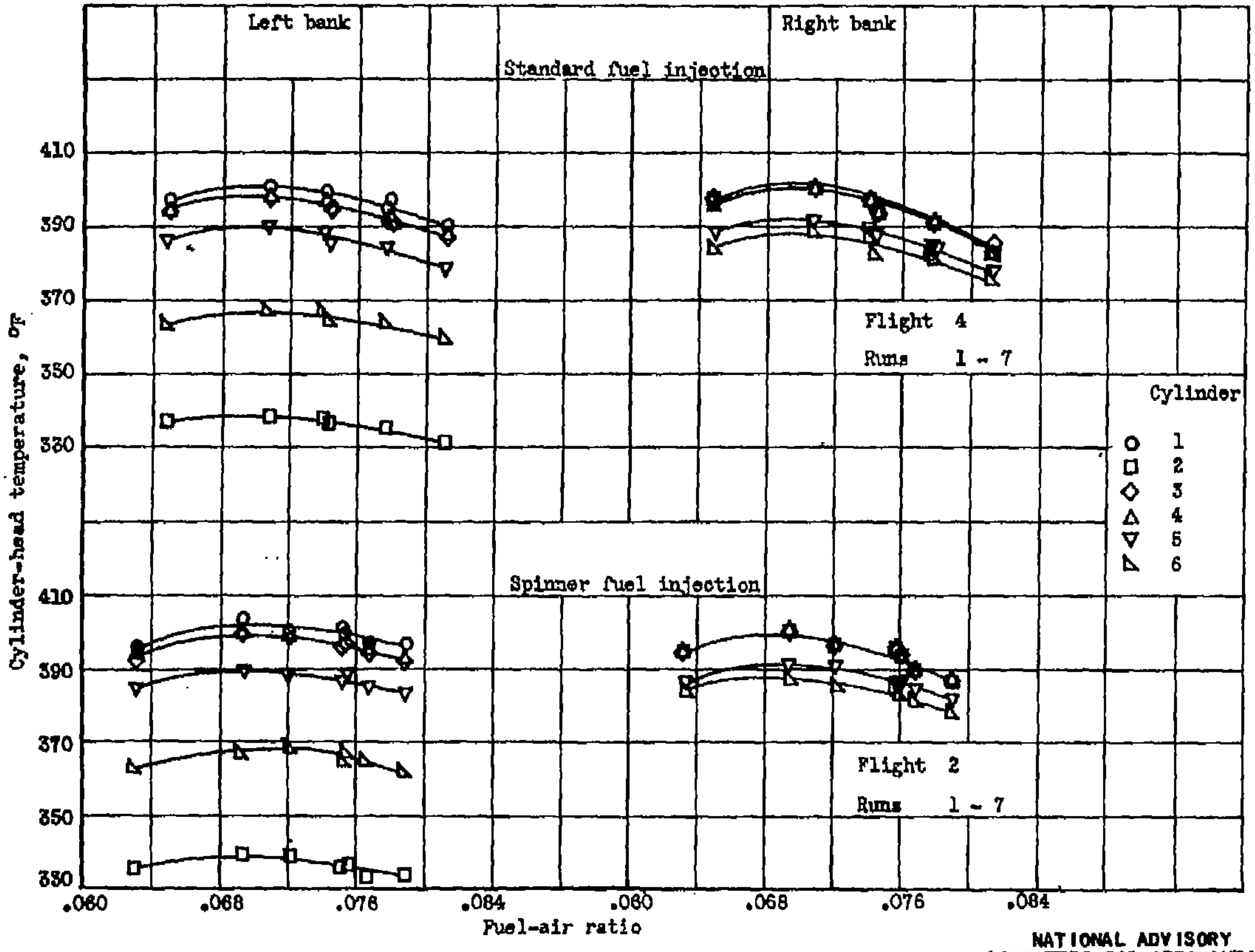


Figure 3. - Section through cylinder head of a V-type, liquid-cooled aircraft engine showing location of cylinder-head thermocouple.



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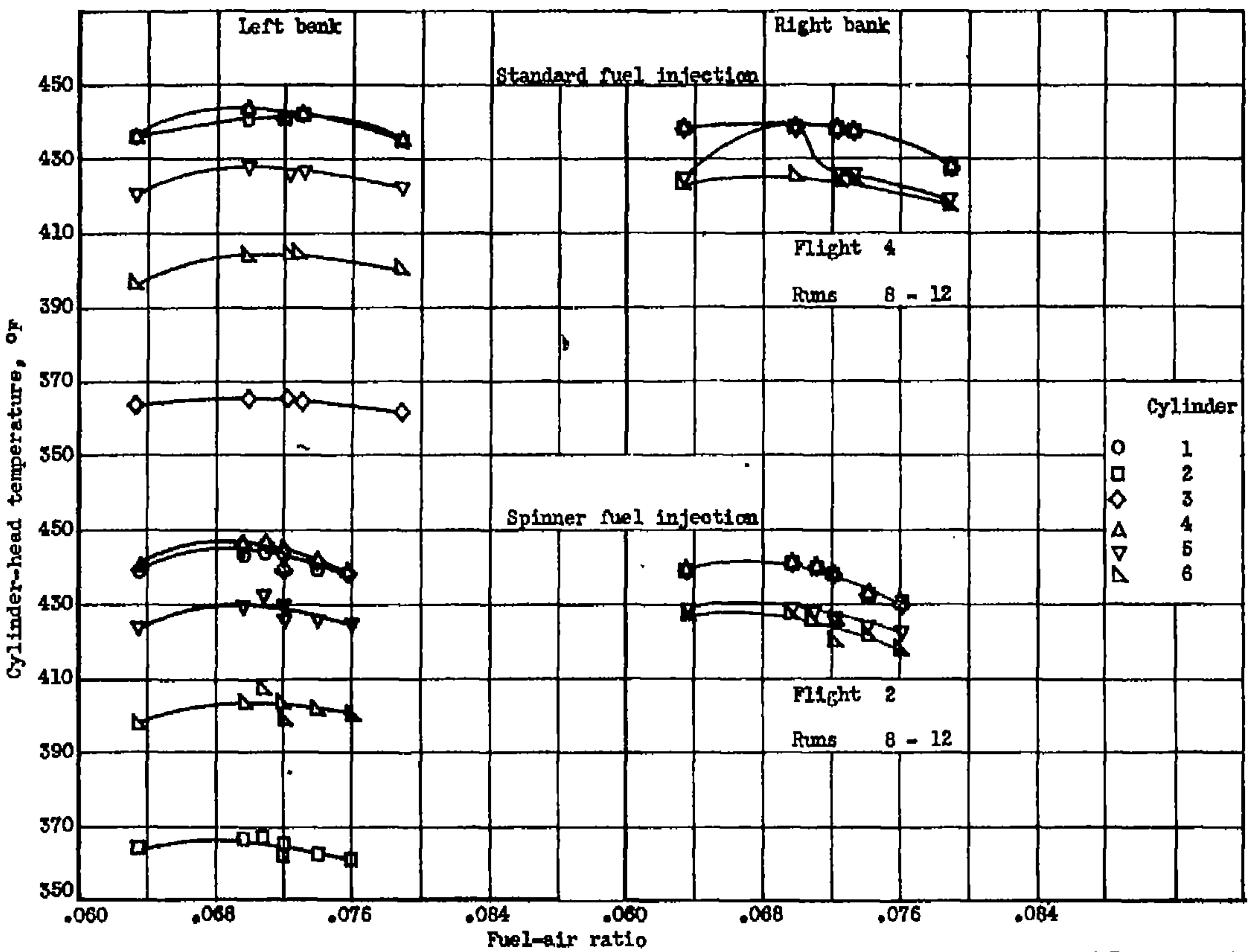
(a) Manifold pressure, 25 inches of mercury absolute.

Figure 4. - Effect of standard and spinner fuel-injection systems on cylinder-head temperatures of V-type, liquid-cooled aircraft engine with varying fuel-air ratio at altitude of 10,000 feet.



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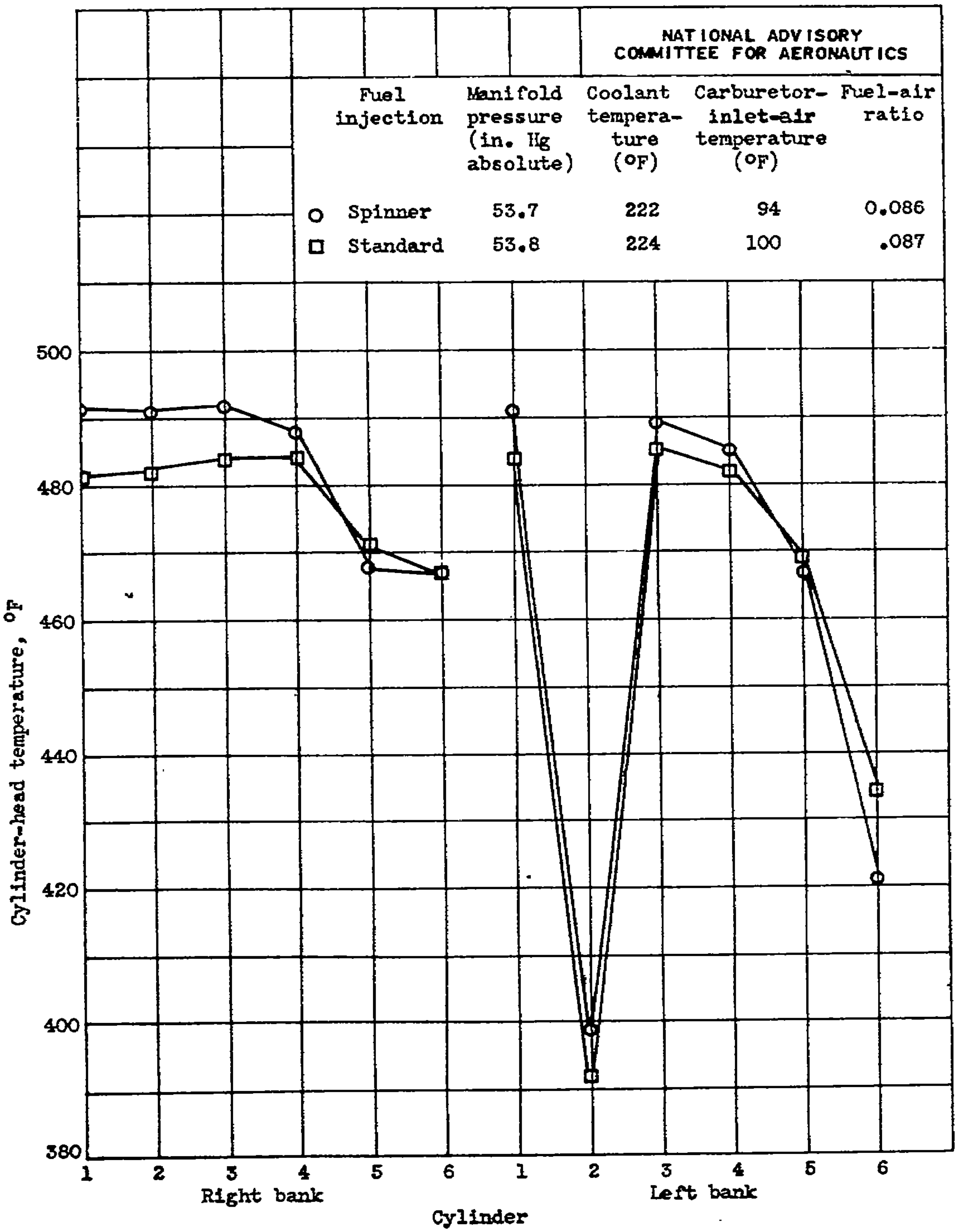
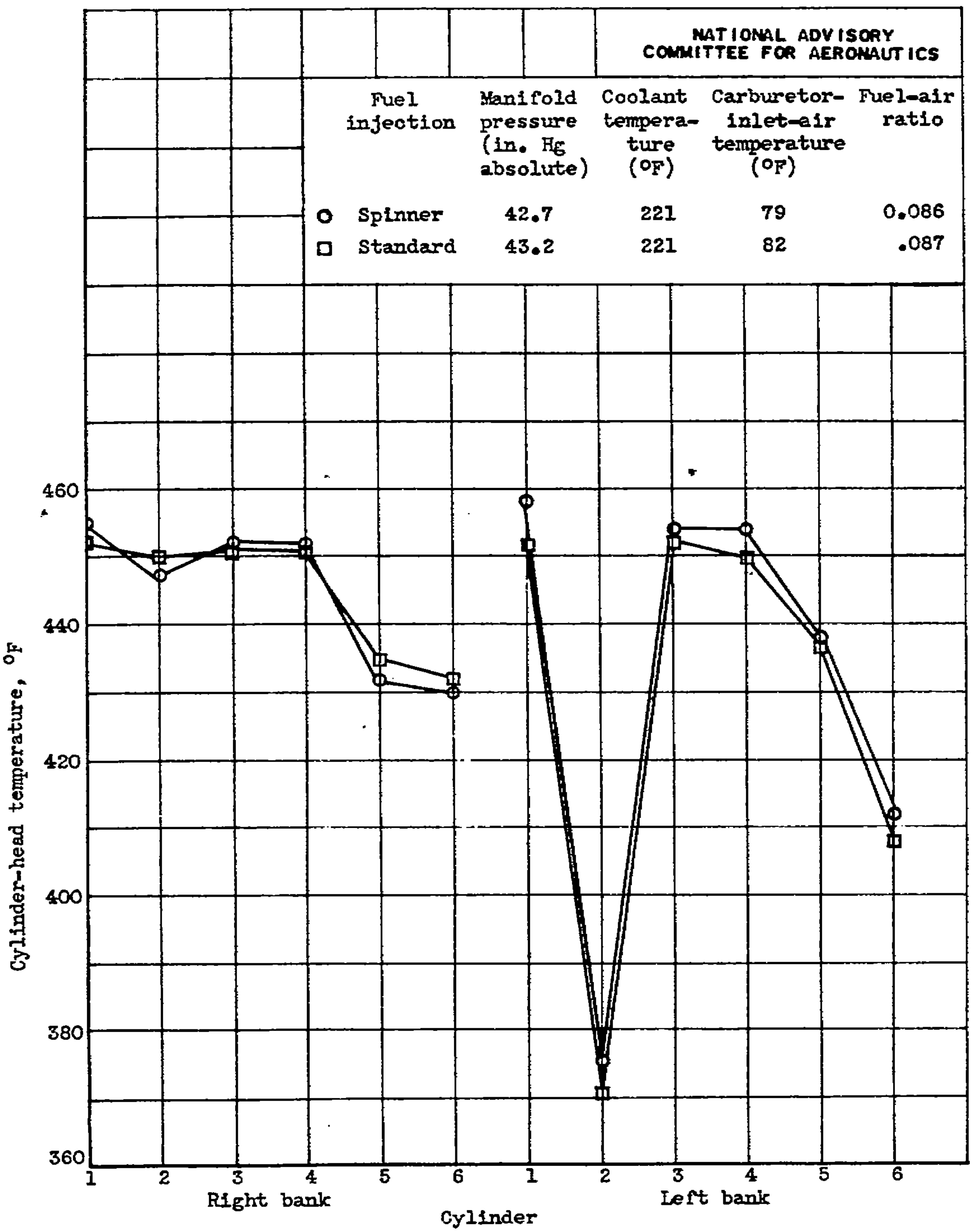
(b) Manifold pressure, 35 inches of mercury absolute.

Figure 4. - Concluded. Effect of standard and spinner fuel-injection systems on cylinder-head temperatures of V-type liquid-cooled aircraft engine with varying fuel-air ratio at altitude of 10,000 feet.



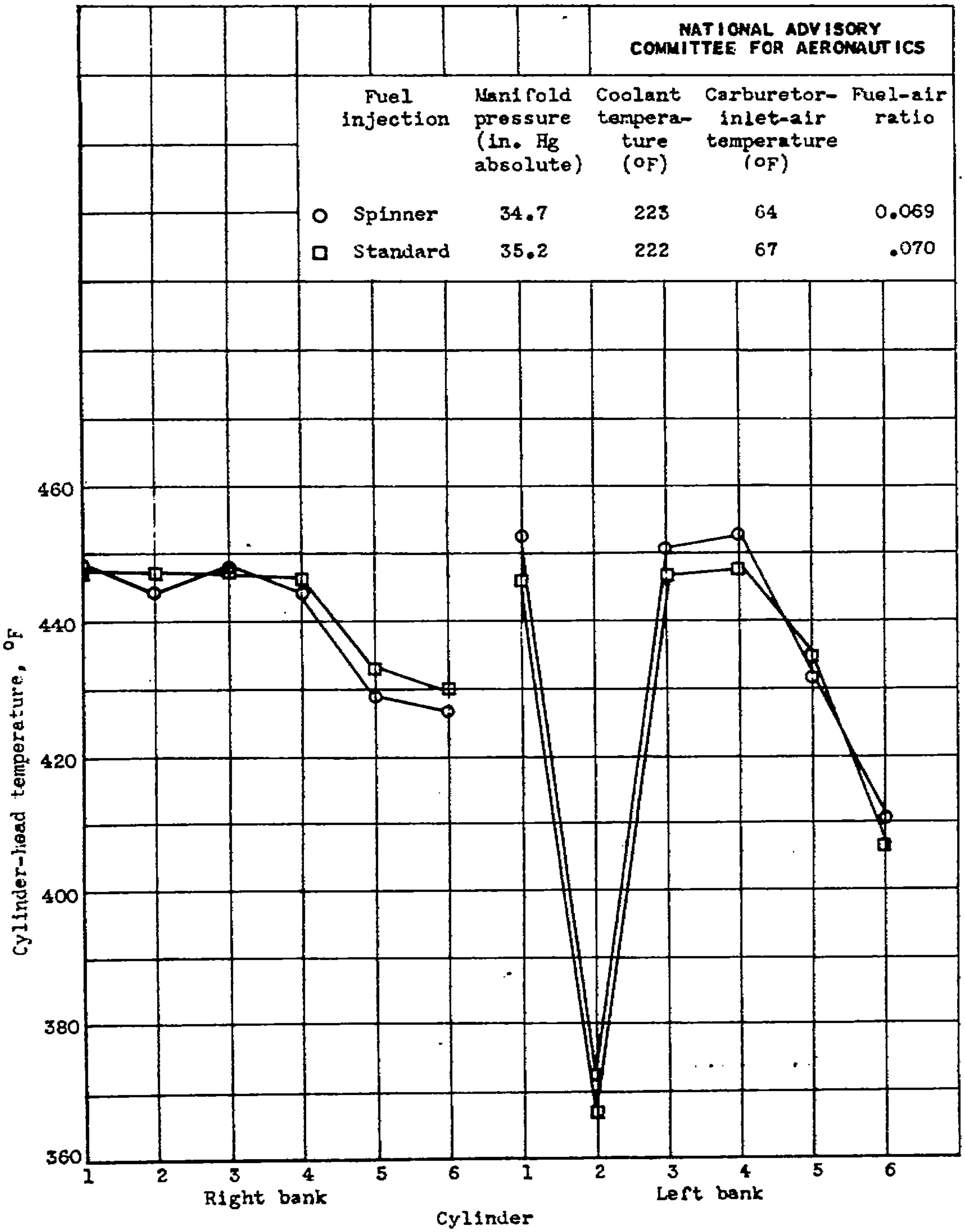
(a) Manifold pressure, 54 inches of mercury absolute.

Figure 5. - Comparison of cylinder-head temperatures of V-type, liquid-cooled aircraft engine at altitude of 10,000 feet using standard and spinner fuel-injection systems.



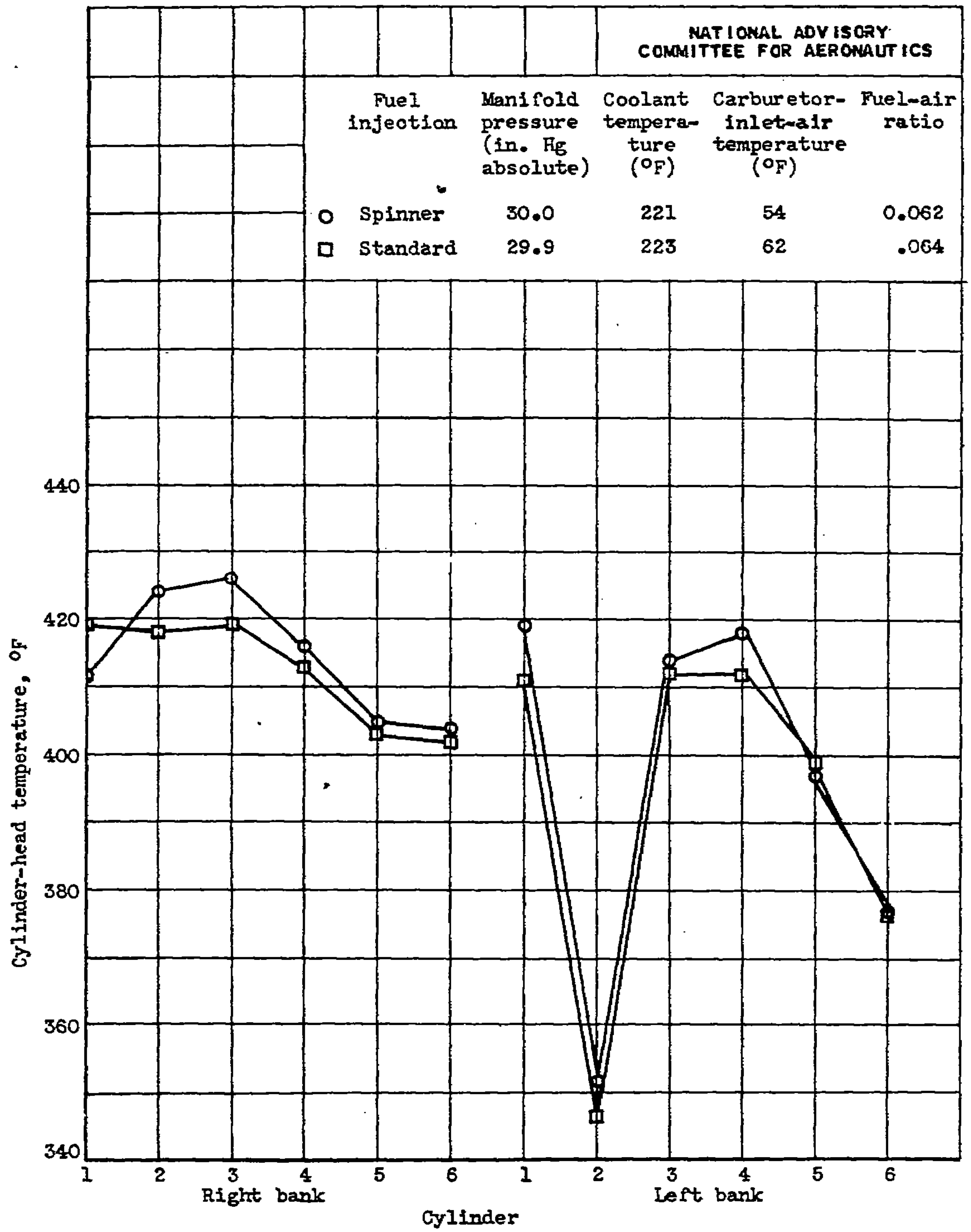
(b) Manifold pressure, 43 inches of mercury absolute.

Figure 5. - Continued. Comparison of cylinder-head temperatures of V-type, liquid-cooled aircraft engine at altitude of 10,000 feet using standard and spinner fuel-injection systems.



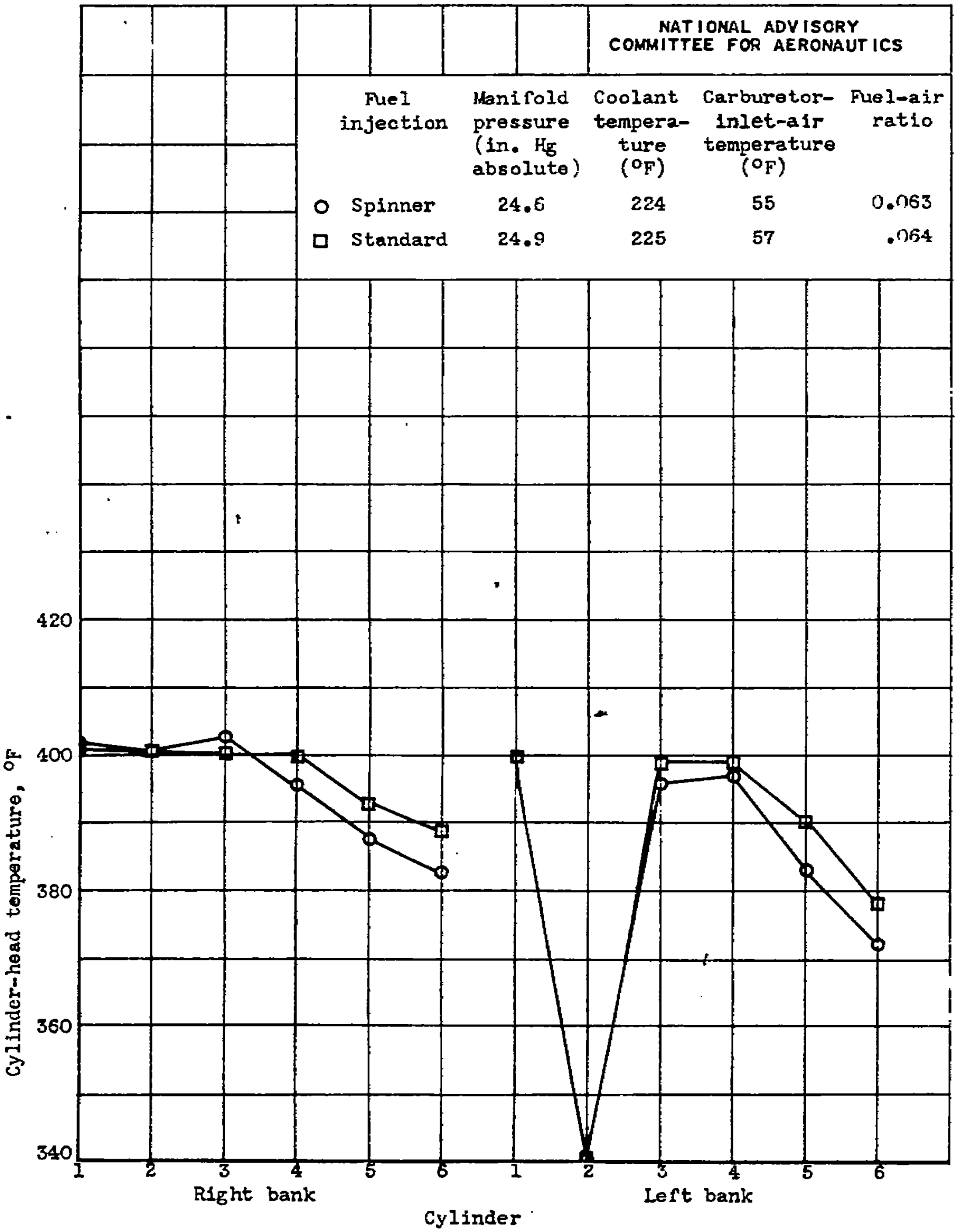
(c) Manifold pressure, 35 inches of mercury absolute.

Figure 5. - Continued. Comparison of cylinder-head temperatures of V-type, liquid-cooled aircraft engine at altitude of 10,000 feet using standard and spinner fuel-injection systems.



(d) Manifold pressure, 30 inches of mercury absolute.

Figure 5. - Continued. Comparison of cylinder-head temperatures of V-type, liquid-cooled aircraft engine at altitude of 10,000 feet using standard and spinner fuel-injection systems.



(e) Manifold pressure, 25 inches of mercury absolute.

Figure 5. - Concluded. Comparison of cylinder-head temperatures of V-type, liquid-cooled aircraft engine at altitude of 10,000 feet using standard and spinner fuel-injection systems.

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